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The CMS Level-1 Tau identification algorithm for the LHC Run II

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Abstract

The CMS experiment implements a sophisticated two-level online selection system that achieves a rejection factor of nearly 10^5. The first level (L1) is based on coarse information coming from the calorimeters and the muon detectors while the High Level Trigger combines fine-grain information from all sub-detectors. To guarantee a successful and ambitious physics program despite the very large backgrounds and proton-proton collision rates, the CMS Trigger and Data acquisition system must be consolidated. In particular the L1 Calorimeter Trigger hardware and architecture will be upgraded, benefiting from the recent microTCA technology allowing the calorimeter granularity to be better exploited in more advanced algorithms. Benefiting from the enhanced granularity provided by the new system, an innovative dynamic clustering technique has been developed to obtain an optimized tau selection algorithm.

Keywords: Level-1 trigger, CMS tau trigger

1. Introduction

After the discovery of the Higgs boson in July 2012 [1][2], an intensive work focussing on the measurements of its properties has started. The H $\to \tau\tau$ channel plays a particular role, as it is the only way to test the Yukawa couplings between the Higgs boson and the leptons predicted in the Standard Model. During the Run 1 of the LHC, no dedicated τ triggers have been used. Indeed, during this period, the jet triggers were used to select τ leptons decaying hadronically. However, this approach will not be adapted to very intense conditions expected for LHC Run II. A dedicated tau trigger will be required to achieve CMS physics goals. The CMS trigger system is organised in two consecutive steps [3]. The hardware-based L1 trigger utilises coarse energy deposits in the calorimeters and in the muon systems to reduce the rate from about 40 MHz to 100 kHz; it is followed by the software-based High Level Trigger (HLT), implementing selection algorithms based on finer granularity and higher resolution information from all sub-detectors in regions of interest identified at L1. The output rate of the HLT is about 1000 Hz.

2. Studies on a new τ Trigger at Level-1

The main idea is to develop a dynamic clustering approach relying on the sole calorimeter information as already developed in the case of the e/γ trigger upgrade [4]. The implementation of such a sophisticated algorithm benefits from the capabilities offered by the new trigger architecture [4]. In order to adapt the e/γ clustering to the selection of tau induced calorimeter signal, a detailed study of the energy deposit profile in ECAL and HCAL was first performed.

2.1. Tau footprint

In order to identify a typical tau energy profile in ECAL and HCAL, a *footprint* had to be produced by looking at the trigger tower energy depositions. In this study Z $\to \tau\tau \to \mu\tau_{had}$ events were selected with $p_T > 20$ GeV. The trigger tower with the highest deposition contains only ~55% of the total energy, instead of ~75% in the case of electrons [4]. Results were also obtained as a function of the pseudorapidity (η) which allowed to conclude that there are no significant differences in the energy shared among the trigger towers.

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2.2. Tau footprint for different decay modes

The algorithm must be designed to handle the multiple decay modes of the τ (τ decays can lead to a low particle multiplicity final state which can produce footprint similar to that of an electron, e.g. $\tau \rightarrow h + \nu$), an event-by-event study of the tau footprint for different decay mode has been carried out. Using the reconstructed τ decay channel it is possible to derive the τ footprint for the events that present a τ decaying respectively into one charged hadron, one charged hadrons plus neutral pions and three charged hadrons. As can be seen from

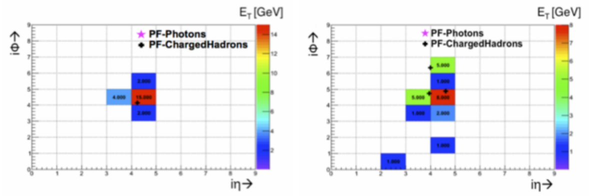

Figure 1: Single event footprint for different τ decay mode: 1-prong (left) and 3-prongs (right).

Fig. 1. In the case of the 1-prong decay mode, a simple clustering algorithm for the τ can be implemented (similar to the one already provided for the clustering of the electron [4]). In fact, the energy deposition involves, in addition to the trigger tower with the maximum deposition, only a second neighbour tower. In this case the algorithm proceeds to clusterize those trigger towers close to the seed that presents an energy deposition in ECAL and HCAL above a certain threshold. The seed is defined as the tower with the local maximum of the ECAL+HCAL energy deposition. Thus, as a first step, a *protocluster* is built centred on the seed. The maximum size of the protocluster is a 3×3 area in the $\eta - \phi$ plane. After this first step, the protocluster is *trimmed*, *i.e.*, one of the two eta slice (1×3) of the *protocluster* is removed if it has a lower energy contribution to the cluster.

2.3. τ-dedicated clustering algorithm:

What emerges from the single event footprint in the case of the 1-prong decay mode (and for the great majority of the 1-prong + π^0 events) is that a protocluster of a 3×3 size is large enough to identify the τ, and thus to define the new τ clustering algorithm. Instead, a specific approach will be required to collect all the energy in the case of the 3-prongs decays. In fact, the energy deposition involves trigger towers that are quite far from each other and, in the ~20% of the 3-prongs decays, there is a ”second maximum” of the deposition in a trigger tower that is outside a 3×3 region around the trigger tower containing the majority of the deposited energy. For such events, a merging algorithm has been adopted. It is capable to merge two e/γ-like clusters centred around two different seeds. The position of the final cluster is the energy-weighted position of the two single clusters.

2.4. L1-τ Calibration

The calibration procedure is carried out in two steps: Firstly an E_T-dependent calibration is performed and, secondly, a residual η-dependent calibration is applied. Since the hadronic τ decays involve also short-living hadrons decaying into γ (like the π^0), the total energy is measured by summing the information from the ECAL and HCAL subdetectors. The responses of these detectors are different and also depend on the nature of the interacting particle. The main goal of the E_T-dependent calibration procedure developed for the τ is to calibrate differently the energy deposited in ECAL from the one deposited in HCAL, following an approach used to calibrate the cluster in the Particle Flow [5]

$$E_{calib} = a(E, h) \cdot E_{ECAL} + b(E, h) \cdot E_{HCAL} + o_{EH} \quad (1)$$

The energy response after the full cluster calibration and the angular resolution, are shown in in Fig.2. The significant improvement in angular resolution in the case of the new τ identification algorithm is due to the higher granularity available with the new trigger architecture. The energy resolution obtained with the new system is comparable to the one obtained during Run-I. This is a remarkable results considering that the trigger towers involved in the the new algorithm represent only ~10% of those used by the algorithm provided during Run-I.

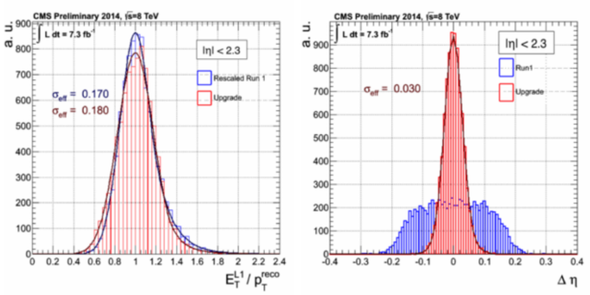

Figure 2: (*left*)Level-1 tau trigger energy resolution for τ in the [-2.3, 2.3] η-region. The energy measurement of the latter has been rescaled to match that of the former. (*right*)Level-1 tau trigger η resolution for L1-taus

2.5. L1-τ Isolation

A crucial aspect in the development of a trigger for hadron collider experiments is the control of the trigger rate. The isolation is a powerful handle to reach such a goal. Indeed, due to the important PU scenario that will be present in the LHC Run-II, the τ cluster can appear not *isolated* in the calorimeters. In this case, a *dynamical isolation algorithm* is implemented for the new L1-τ. The transverse energy in the isolation region is computed in a $\eta \times \phi = 5 \times 9$ area around the L1-τ after the subtraction of the transverse energy assigned to the L1-τ itself. The region corresponding to the L1-τ is dynamically assigned accordingly to the cluster shape information and their relative positions in case of 2 merged clusters.

3. Performance of the new L1-τ trigger

The new trigger algorithm for L1-τ has been emulated directly on real data: an integrated luminosity of 7.3 fb^{-1} from 2012 Run D 8 TeV data is used. The sample of hadronically decaying τ reconstructed offline, used as reference, is constituted applying a $Z \rightarrow \tau\tau \rightarrow \mu - \tau$ tag-and-probe selection. It requires a well-identified tag τ decaying into muon and a probe tau decaying hadronically, as well as opposite charges and finally a [42.5 GeV, 72.5 GeV] mass window requirement. The trigger efficiency as a function of the offline tau calorimetric transverse energy (i.e. *turn-on curves*) is one of the figure of merit that have been produced. The new algorithm presents *turn-on curve* reaching an efficiency at plateau of ~100% for different L1-τ transverse energy threshold. In Fig. 3 *turn-on* corresponding to the 30 GeV working point are presented. Noteworthy is the comparison with the previous L1-τ algorithm: because of the presence of shape vetos[3] the trigger efficiency is limited to ~75% in the best configuration (barrel) and decrease ~30% in the endcaps. Another important figures of merits are the comparison between *ROC-curves*, where the trigger efficiency is plotted against the corresponding background rejection for different working points. The comparison between the Run-1 system and the upgraded system for Run II, reported in Fig.4(*left*) shows that a 35% increase on background rejection is achieved for an equivalent signal efficiency. A more detailed treatment of the background reduction is presented also in Fig.4(*right*).

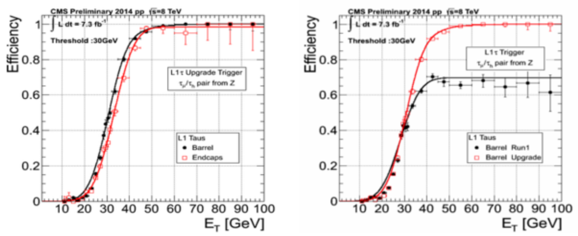

Figure 3: *Turn-on curves for Stage-2 (for different η) and Run1.*

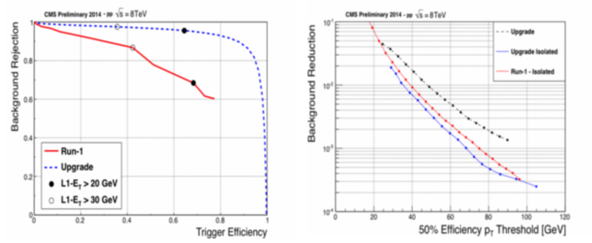

Figure 4: (*left*) *ROC curves* (two particular working points are shown in the curves: 20 GeV (black) and 30 GeV (white circle)). The stage-2 upgrade algorithm (dashed-blue) is compared to the Run 1 algorithm (red). (*right*) Level-1 tau background reduction for L1 Et thresholds above 20 GeV.

As a conclusion, the new τ identification algorithm shows enhanced performance with respect to the one used during the Run 1 of the LHC. The τ trigger selection technique presented here demonstrates a stable rate in the intense PU environment expected during the LHC Run-II.

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